Electra

A Repetitively Pulsed, High Energy, Krypton Fluoride Laser

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The Electra Program will develop the Science & Technology required to build a KrF for Laser Inertial Fusion Energy

Build a new 5 Hz, 700 J laser (Electra)

Perform R & D needed for laser components

Build laser by integrating each component as it is developed

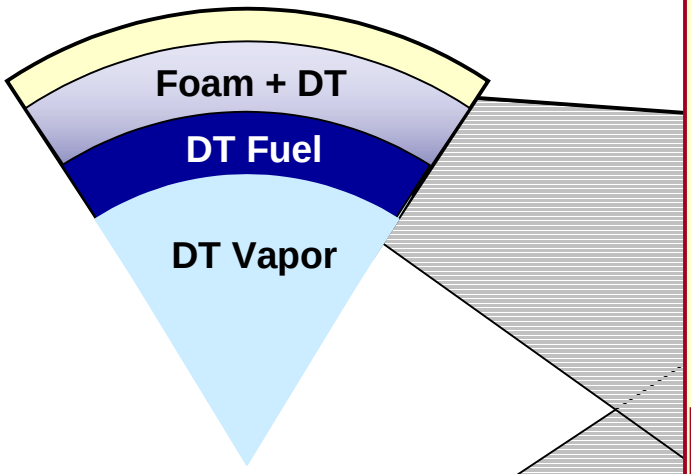
Augment with research on Nike to validate scaling to larger system

Use technologies that can be scaled to ultimate goals:

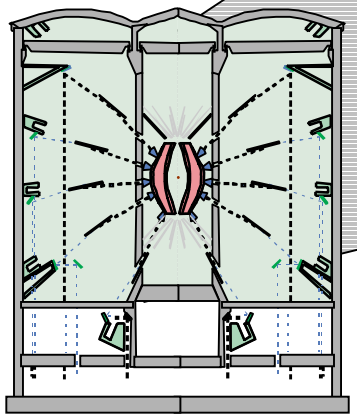
laser energy	**50-150 kJ**
durability	**3 x 10^8 shots**
efficiency	**6-7 %**
cost	**< $ 225/J**
beam quality	**< 0.2% high mode**

Target gain and power plant studies define the laser requirements

High Gain Target Design (G >100) [1]



Power Plant Study [2]



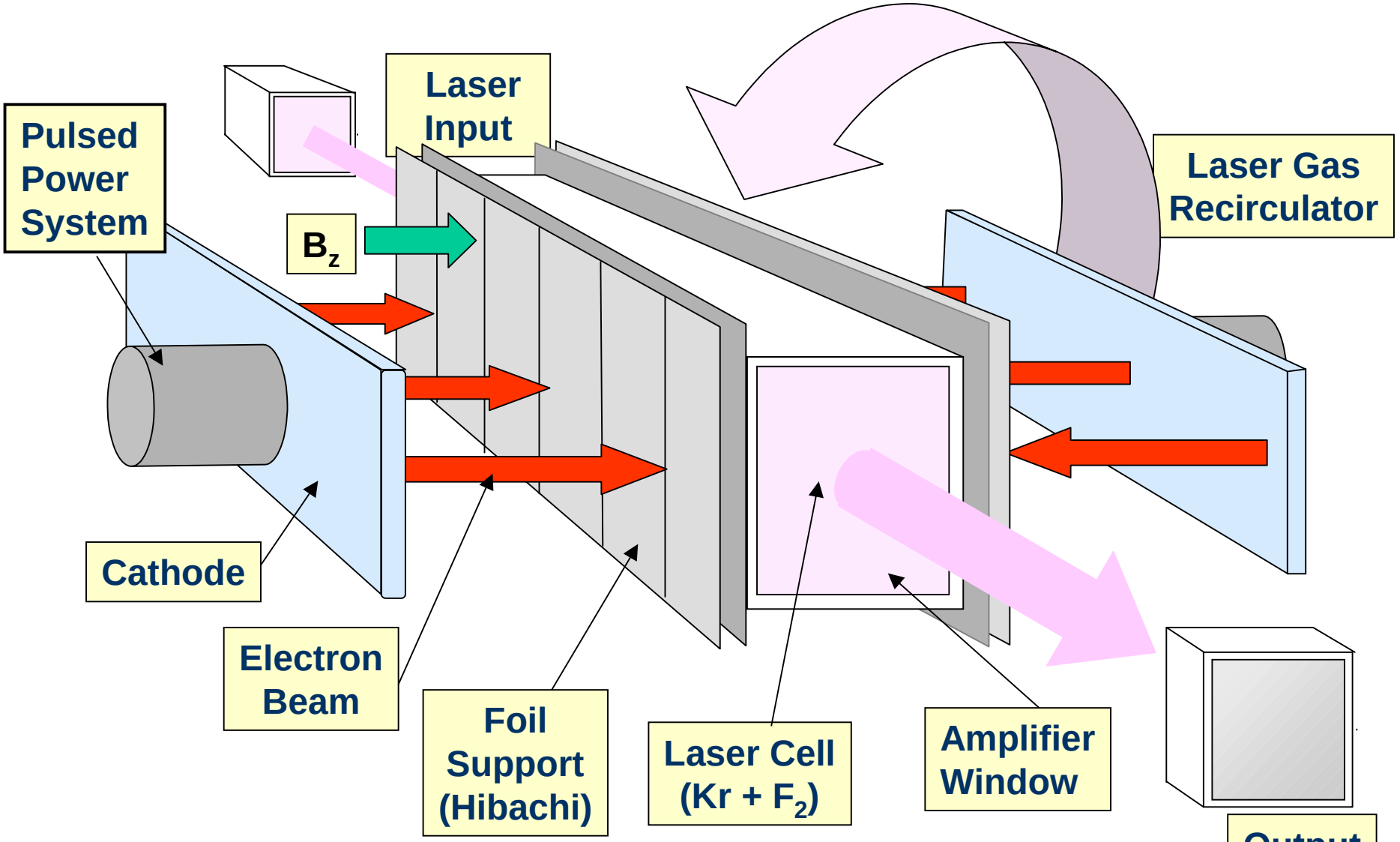
Laser IFE Requirements

	IFE	NIKE
Beam quality (high mode)	0.2%	0.2%
Beam quality (low mode)	2%	N/A(4)
Optical bandwidth	1-2 THz	3 THz
Beam Power Balance	2%	N/A(4)
Laser Energy (amplifier)	30-150 kJ	5 kJ
System efficiency	6-7%	1.4%
Cost of entire laser(1)	$225/J(laser)	$3600/J
Cost of pulsed power(1)	$5-10/J(e-beam)	N/A3
Rep-Rate	5 Hz	.0005
Durability (shots) (2)	3×10^8	200
Lifetime (shots)	10^{10}	10^4

1. 1999 $. Sombrero (1992) gave $180/J and $4.00/J
2. Shots between major maintenance (2.0 years)
3. Not Applicable: Different technology
4. Not Applicable: Nike shoots planar targets

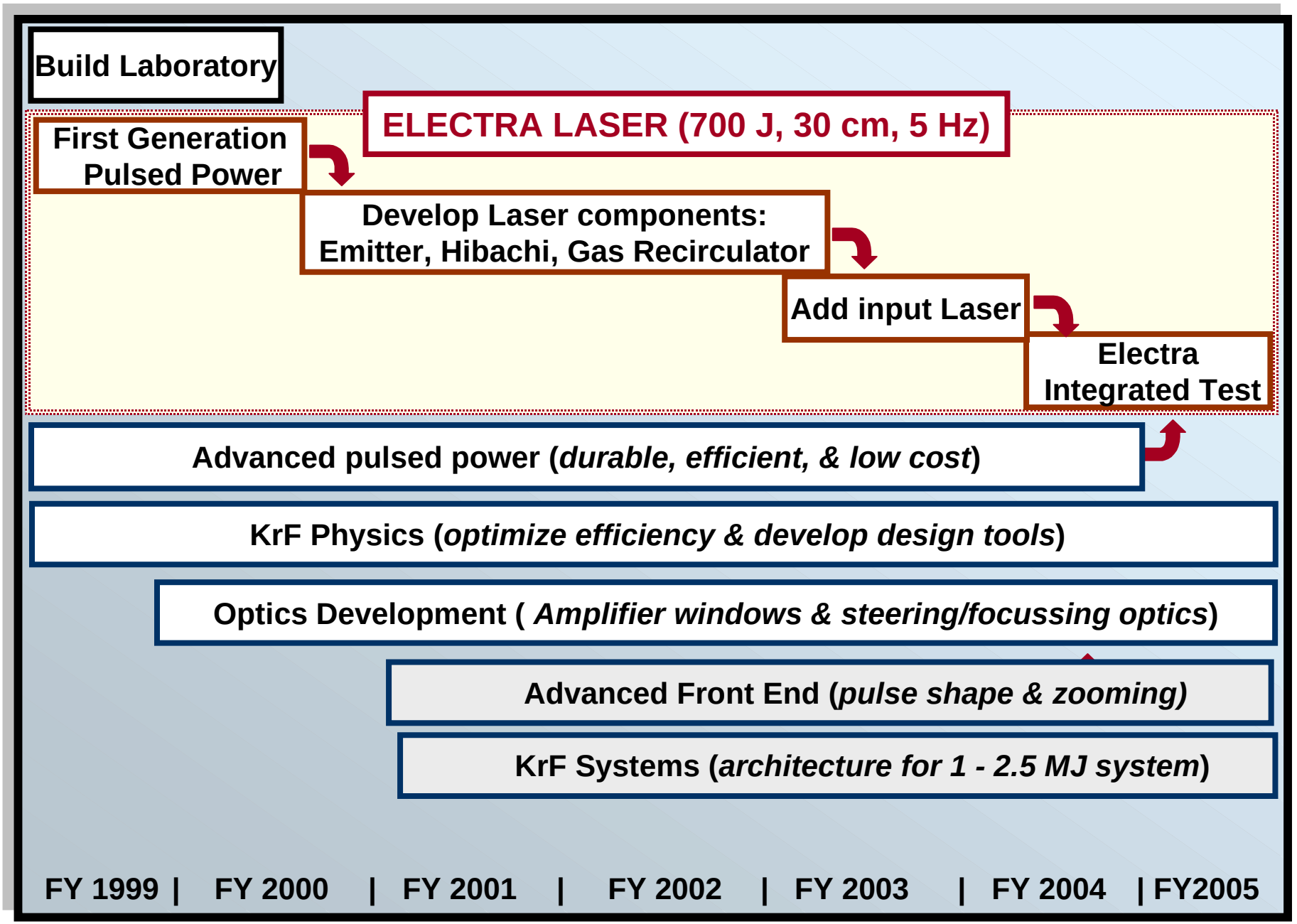
1. S.E. Bodner et al, ."Direct drive laser fusion; status and prospects", *Physics of Plasmas* **5,** 1901, (1998).
2. Sombrero: 1000 MWe, 3.4 MJ Laser, Gain 110; Cost of Electricity: $0.04-$0.08/kWh; Fusion Technology, **21**,1470, (1992)

The Key Components of a Krypton Fluoride (KrF) Laser



$$\text{ENERGY} + (Kr + F_2) \Rightarrow (KrF)^* + F \Rightarrow (Kr + F_2) + h\nu\ (248\ \text{nm})$$

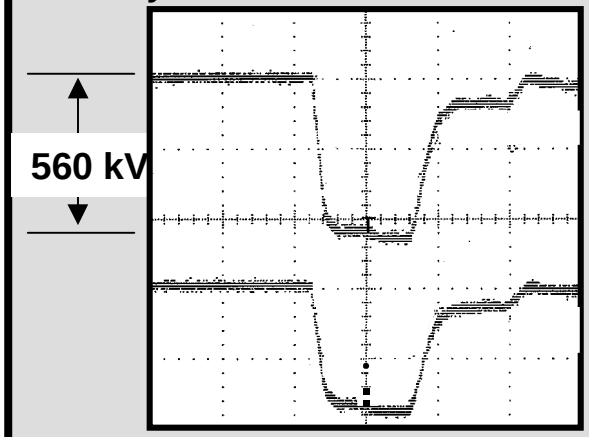
The Electra Program Plan



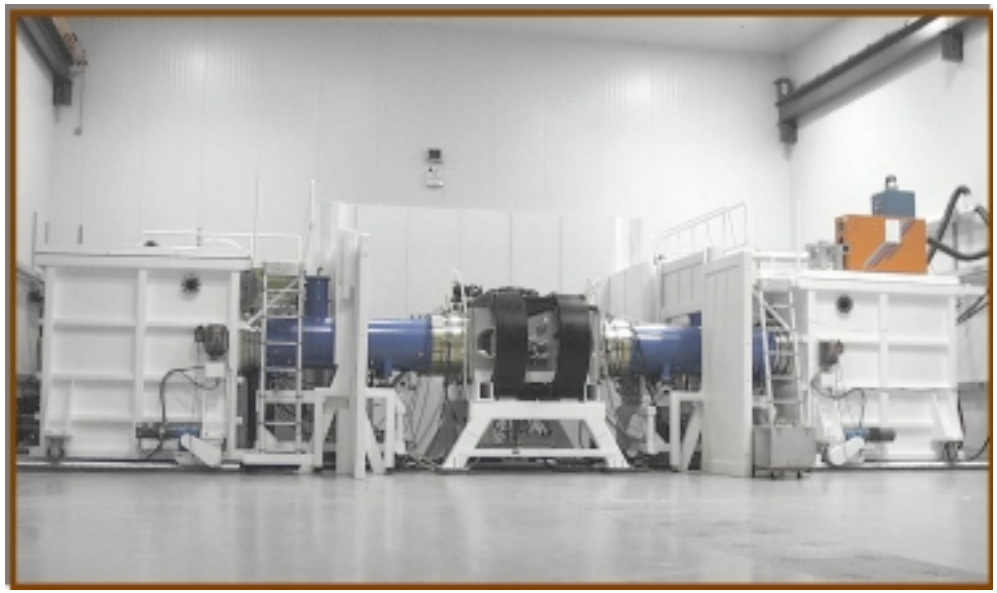
First Generation system can run at 5 Hz for 5 hours
Excellent test bed for developing laser components

Results from Testing at PSI on "south side"

Output voltage
overlay of 20 shots @ 5 Hz, full volts



89,000 shot run @ 5Hz ~ 5 hours



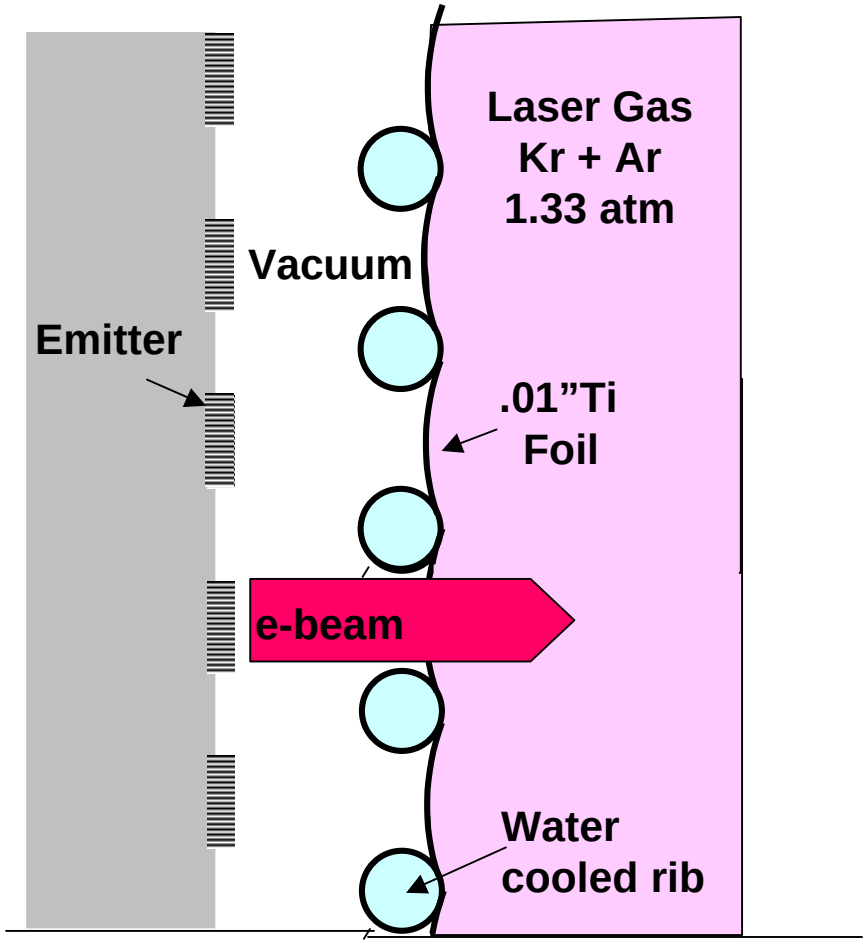
Number of Shots to date:

South:	**250,000 shots**
North (NRL):	**35,000 shots**
Together:	**3 x 1000 shots**

TITAN PSI
PULSE SCIENCES INCORPORATED

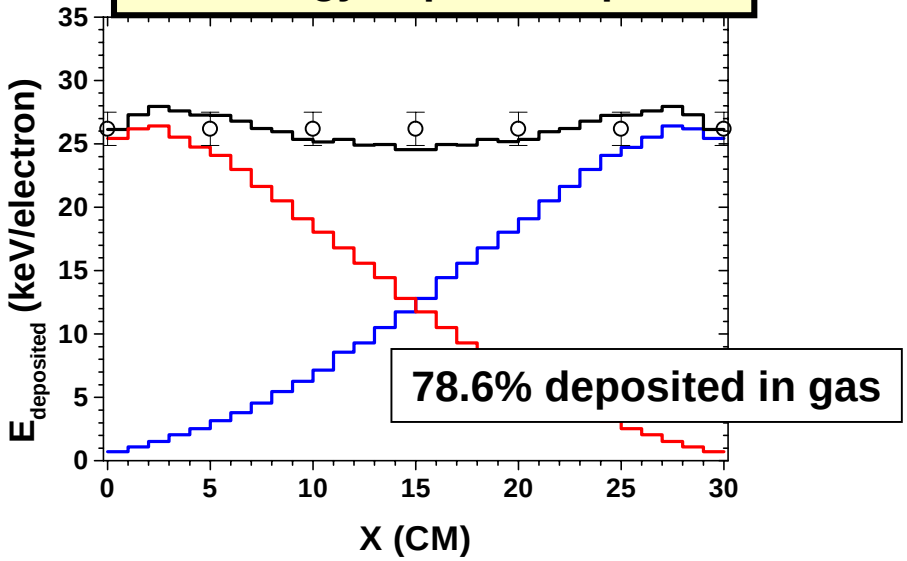
We are developing the emitter & hibachi as a single system

Pattern emitter to miss hibachi ribs

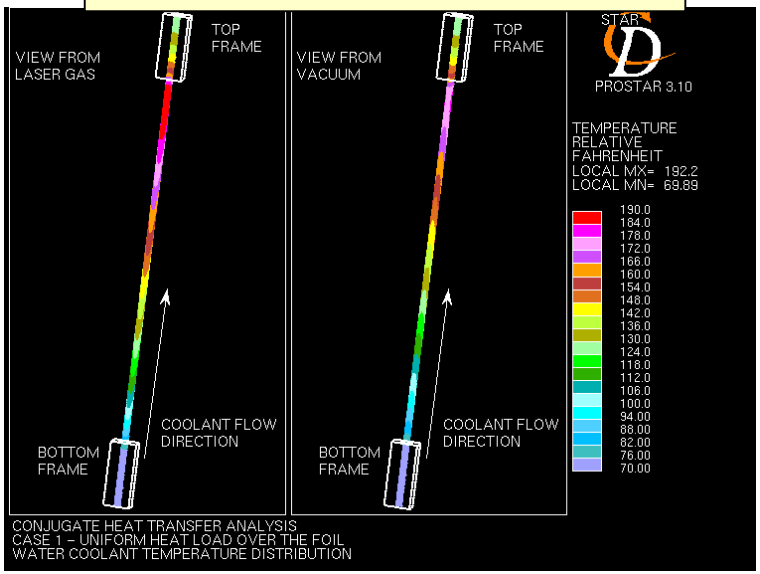


Foil loading ~ 0.9 W/cm^2

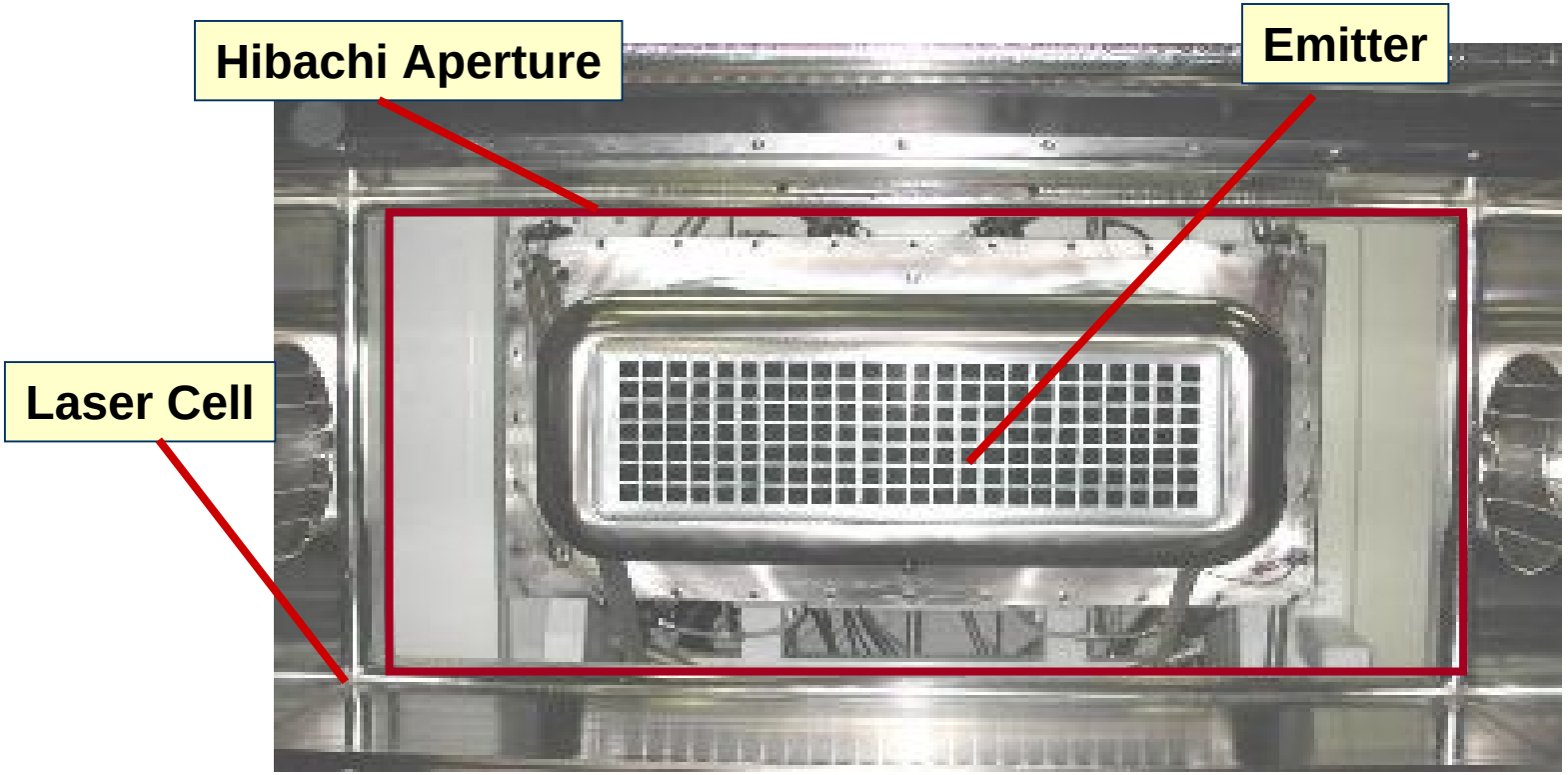
1-D Energy deposition profile

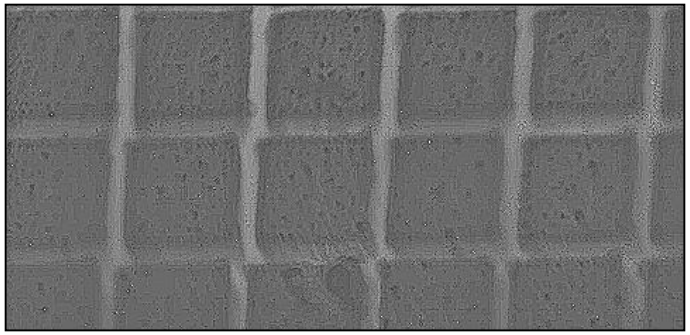


CFD analysis of cooled ribs

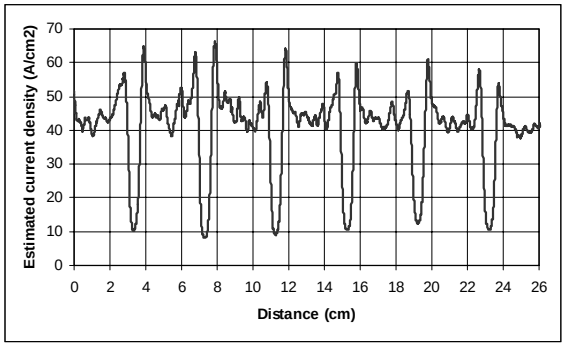


We have made many types of patterned electron beams





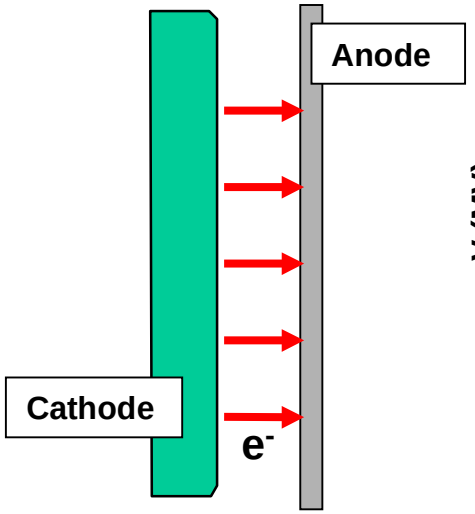
Radiachromic Film



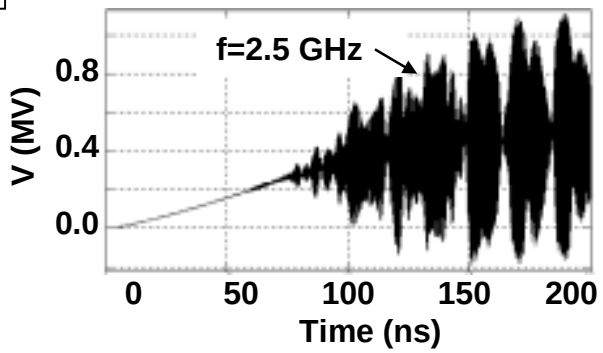
Line out of RC film

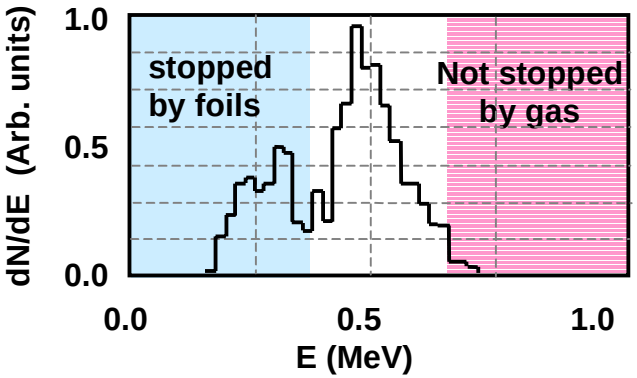
2D PIC simulations predict that resistive tuned slots in the cathode stabilize the "transit time" instability

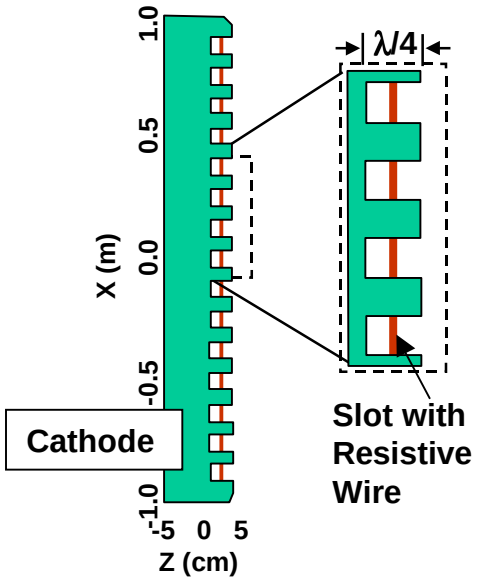
NRL



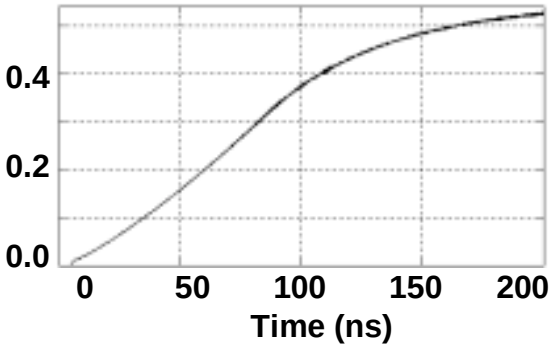
Before

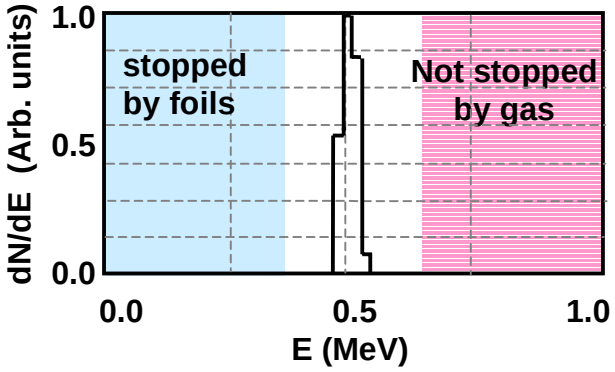






After





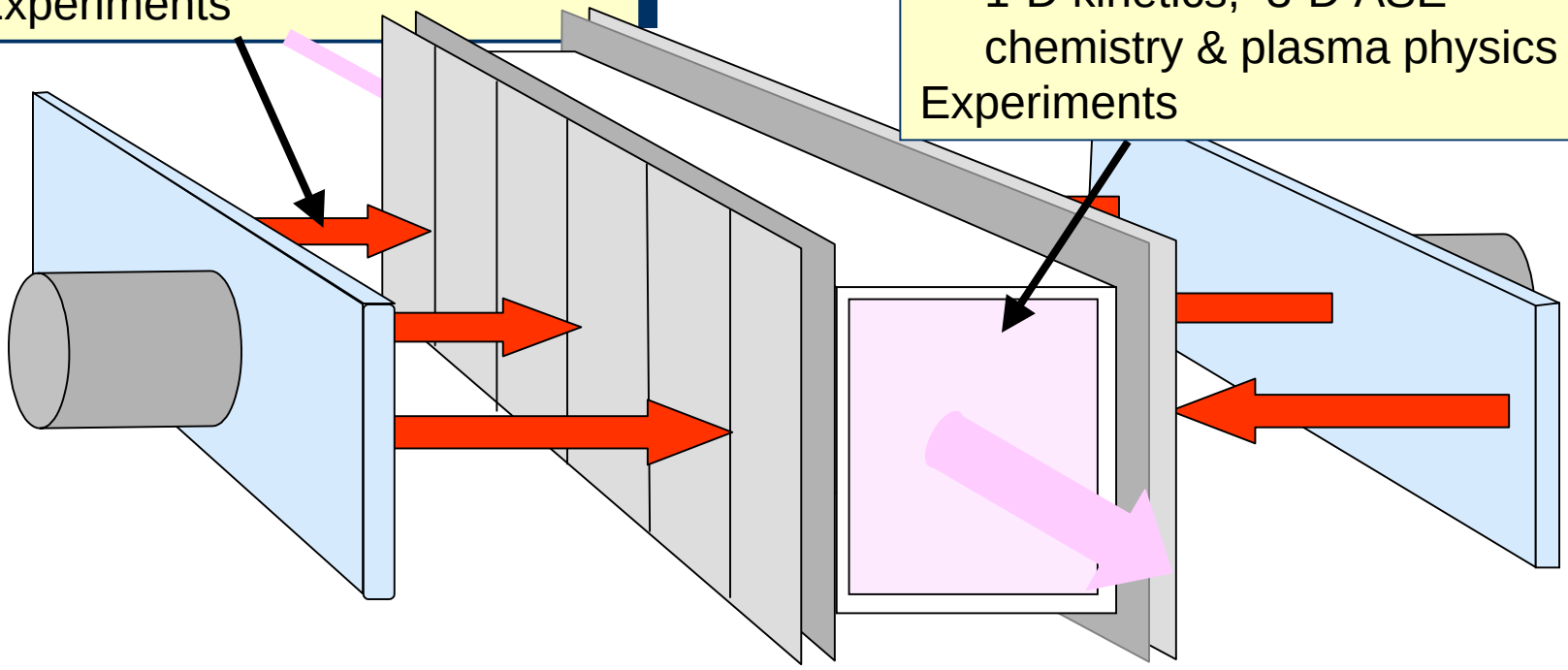
KrF Physics: develop predictive capability for large KrF systems

Electron Beam Propagation
- transport in diode & hibachi,
- deposition in gas
  - 2-D, 3-D PIC code modeling
  - 2-D simulations

Experiments

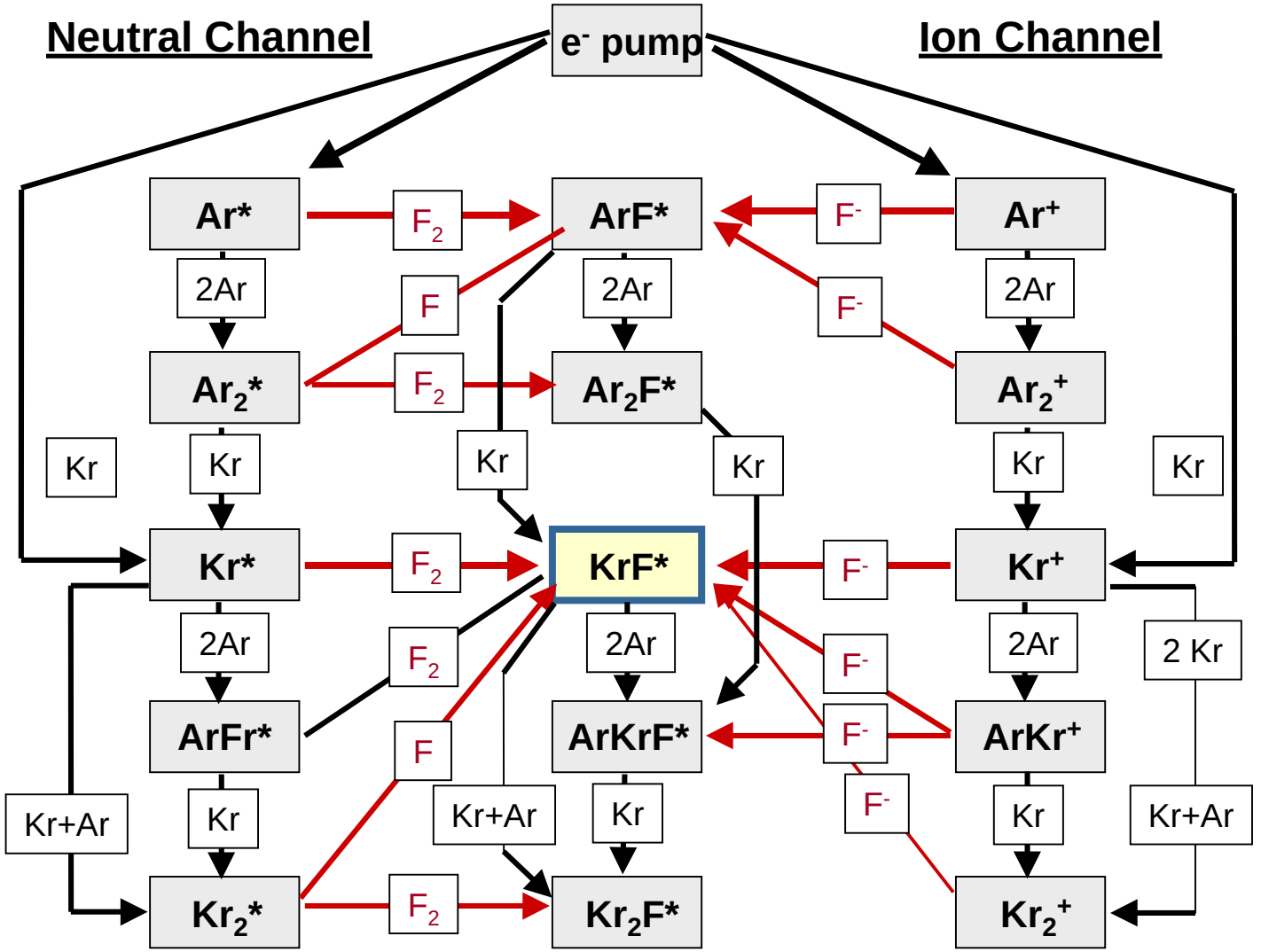
Laser Amplifier Physics
- e beam to KrF^*
- laser transport
  - 1-D kinetics, 3-D ASE
  - chemistry & plasma physics

Experiments



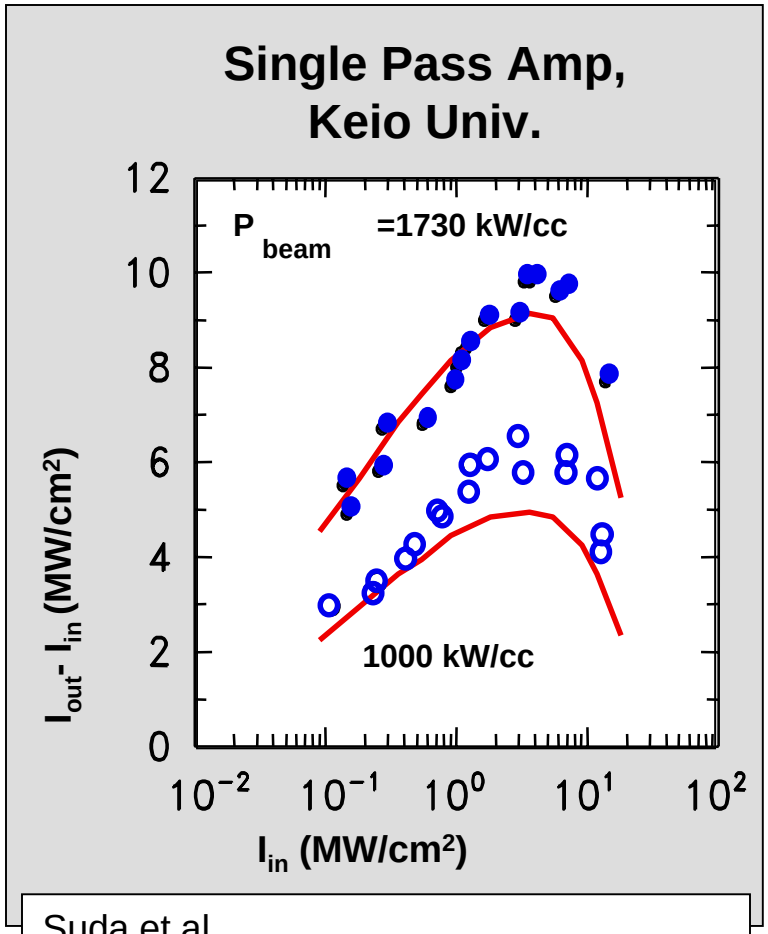
KrF Physics done on both Nike and Electra

KrF Kinetics is a multi species process



Adopted from Johnson & Hunter, J. Appl. Phys,. 31 p 2046 (1980)

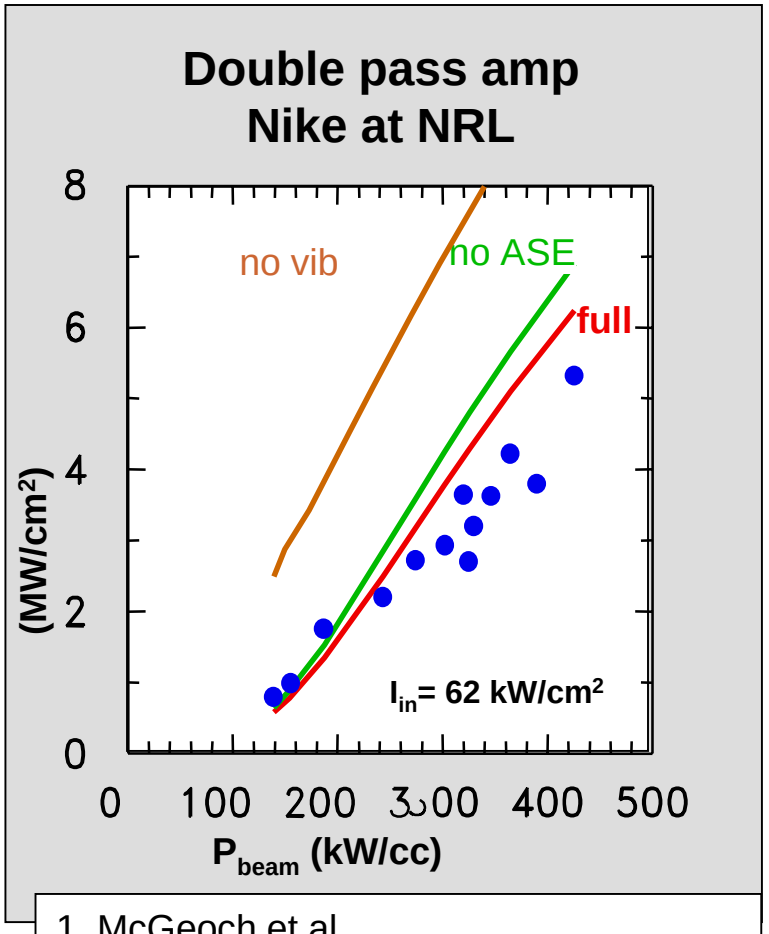
The Kinetics/ASE model compares favorably with experimental data under diverse conditions



Suda et al
Appl Phys Lett **51,** 218 (1987)

● 99.4% Kr + 0.6 % F_2 + 0 % Ar @ 1 atm

○ 10% Kr + 0.4% F_2 + 89.6% Ar @ 1 atm



1. McGeoch et al
   Fusion Tech, 32 610 (1997)
2. Sethian et al
   Rev Sci Instrum, **68,** 2357 (1967)

● 35% Kr + 0.4% F_2 + 64.6% Ar @ 1 atm

Advanced pulsed power development plan

Pick nominal module size of 100 kJ pulsed power = 80 kJ e-beam

	First design	Range
Voltage:	800 kV	650-900 kV
Current:	150-200 kA	150-350 kA
Module size:	100 kJ (electrical)	50-150 kJ
Pulse Length:	600 nsec	200-1500 nsec

Evaluated pulsed power concepts that can meet the requirements:

Cost:	$5.00-10.00/electron beam Joule
Efficiency:	> 80%
Durability:	> 3 x 10^8 shots

Use systems studies to determine feasibility and define R & D

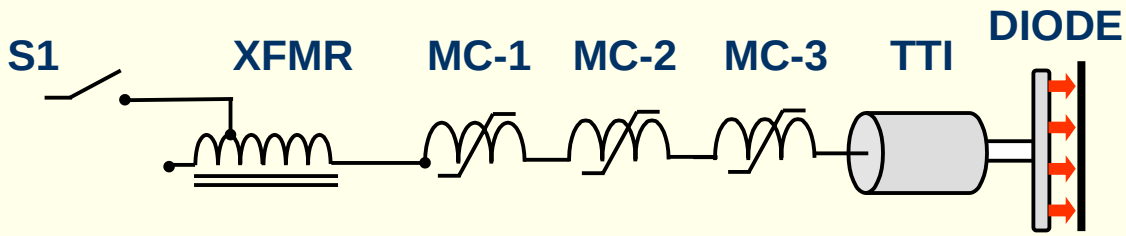
Develop the required components - 3 yrs

Integrate into system that demonstrates technology on Electra - 2 yrs

We are evaluating three advanced pulsed power systems, and performing R & D to develop the required components

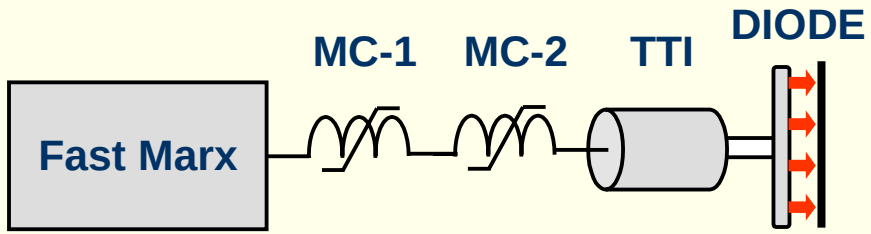
Transformer + 3 stage Magnetic Compressor

Cost [1] Efficiency[2]



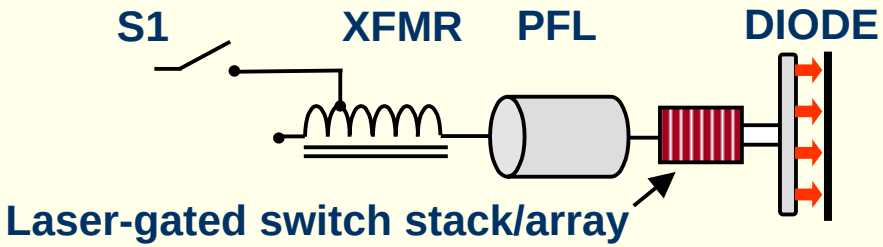
$11.30/J **81%**

Fast Marx w/ laser gated switches + 2 stage Magnetic Compressor



$ 7.65/J **85%**

Transformer + PFL + HV laser output switch



$ 8.35/J **87%**

1. $ / e-beam Joule, for 100 kJ system in quantities, NOT Electra; 2. Flat top e-beam/wall plug

Meeting the IFE efficiency requirements is a challenge… but achievable

Efficiency Goal: 6-7%

Efficiency allocation:		How we get there	Current status
Pulsed power	80%	Advanced PP design	RHEPP 63%
Hibachi	80%	Suspension Bridge & KrF Physics	LANL~ 90% (Nike 50%)
Ancillaries	95%	Electra + Study[1]	N/A
Intrinsic	10-12%	KrF physics[2]	14-15%(small systems)[3,4] 12% predicted from Nike kinetics code[5] 7% Nike (not optimal η)
TOTAL	6-7%		

1. Electra will validate technology. Efficiency and cost will be established with modeling from Electra results
2. $\eta_{intrinsic} = \eta_{formation}$ (25-28%) x $\eta_{extraction;}$ (40-50%) = (10-14%). Optimize extraction by increasing gain-to-loss
3. "KrF Laser Studies at High Krypton Density" A.E. Mandl et al, Fusion Technology 11, 542 (1987).
4. Characteristics of an electron beam pumped KrF amplifier with atmospheric pressure Kr-rich mixture in strongly saturated region", A. Suda et al, Appl. Phys. Lett, 218 (1987)
5. M.W. McGeoch et al, *Fusion Technology*, 32, 610 1997

(KrF) Laser IFE Integrated Research Experiment

The IRE is envisioned to be an integrated repetitive demonstration that:

1. **A Cryogenic, layered target can be injected into a target chamber environment. And survive.**

2. **A power plant-sized laser beam line (e.g. 50-100 kJ)can be steered to illuminate the target.**

3. **The entire system can operate with the efficiency, durability, uniformity and & precision required for Inertial Fusion Energy.**